Fermilab

UPC 116

GUIDELINES FOR THE FIELD QUALITY OF DOUBLER QUADRUPOLES

S. Ohnuma

November 19, 1979

The word "guideline" has been in use to designate a set of conditions to be met by the doubler magnets. It is meant to be more flexible than "criteria" and also to be subject to changes from time to time. Since no quadrupoles of TQ-series have been measured so far, there is a definite danger of setting down unrealistic requirements at this time. On the other hand, the field quality of doubler dipoles is well established and this enables us to think about a reasonable range of parameters. In general, whenever a direct comparison is possible, effects of quadrupoles on the beam should not be more than the effects arising from dipoles. At the same time, it is not meaningful to demand that the quadrupole effects be less than 5% of the dipole effects. Whether they should be less than 50% or less than 20% is of course a debatable point and there is no rigid line one can draw. Practical difficulties in meeting various types of tolerance will inevitably play an important (if not the decisive) role. Another boundary condition is the already fixed capability of the correction system. In order to maintain a flexibility of operation, effects coming from quadrupoles alone should not use up a major fraction of the total strength of correction magnets.

In the normal doubler lattice, there are 180 regular quadrupoles with the nominal effective length of 66.1" and 36 special quadrupoles with lengths ranging from 25.5" to 99.4". The amplitude function $\beta_{x,y}$, which are less than 100 m at regular quadrupoles, can be as large as 245 m in some of these special quadrupoles and effects coming from them may become disproportionally large for some phenomena. This is especially true if modifications are made to the standard lattice for the colliding modes. The guidelines given in this note are all for the regular quadrupoles only. As we build and install some number of regular quadrupoles, guidelines for the special quadrupoles can be specified in a sensible manner.

A. Error in the quadrupole magnetic center

This is the combination of the measurement error and the error in referencing the center to the external fiducial mark. In addition, there will be an installation misalignment. These, together with the dipole median plane rotation and the fluctuation in the integrated bend field among dipoles, contribute to the closed-orbit distortions.

Guidelines

1. Horizontal ($\nu = 19.4$, x_c at $\beta_x = 100$ m)

field variation	$(\Delta B\ell/B\ell)_{rms} = 0.05\%$,	$(x_c)_{rms} = 3.2$ mm
alignment error (rms)	= 30 mil	= 11.6 mm
centering error (rms)	= 10 mil	= 3.9 mm
		combined $(x_c)_{rms} = 12.6$ mm

2. Vertical ($\nu = 19.4$, y_c at $\beta_y = 100$ m)

median plane error* (rms)	= 1.8 mrad	$(y_c)_{rms} = 11.6$ mm
alignment error (rms)	= 10 mil	= 3.9 mm
centering error (rms)	= 10 mil	= 3.9 mm
		combined $(y_c)_{rms} = 12.8$ mm

The position of the magnetic center should be available to people installing the magnet with the rms error within 10 mil in both directions and the misalignment (from one quadrupole to the next) should be less than

---

* If the tilt is systematic, max. $|y_c|$ = 6.8 mm at stations #27 and the average value of $|y_c|$ at all vertical stations = 3.9 mm, both for the systematic tilt angle of 1 mrad.

the values specified above. It is hoped that these values are rather lenient (no challenge?). For dipoles installed in the tunnel up to now, the rms value of $(\Delta B\ell/B\ell)$ is less than 0.05%. As for the median plane uncertainties, we will have to wait for a good news about the new design of cryostats. Rotational misalignments during the installation are by no means trivial.

B. <u>Error in the magnetic axis of quadrupoles</u> (angle θ)

This may turn out to be the most difficult one both in the measurement and in controlling the change due to warmup-cooldown cycles. For $\nu_x - \nu_y = 0$ and $\nu_x + \nu_y = 39$ resonances, the magnitude of the coupling parameter c is given by

$$|c|_{rms} = 4.35\times\theta_{rms}$$

<u>Guideline</u> $\theta_{rms} = 3$ mrad (all errors, including misalignment)

1. $\nu_x - \nu_y = 0$

From the average skew quadrupole component in dipoles	$|c| = 0.032$
From $2\times\theta_{rms} = 6$ mrad	$|c| = 0.026$
combined	$|c| < 0.058$

total correction skew field required at 1 TeV/c : $\int B' d\ell = 460$ kG.

2. $\nu_x + \nu_y = 39$

From twice the rms of skew quadrupole in dipoles	$|c| = 0.015$
From $2\times\theta_{rms} = 6$ mrad	$|c| = 0.026$
combined	$2\times|c|_{rms} = 0.030$

total correction skew field at 1 TeV/c, two sets,

$\int B' d\ell$ for each set < 240 kG.

At present, eighteen correction skew quadrupoles with $\int B' d\ell = 60$ kG each are expected to be installed. Although this seems to be adequate for the compensation of two coupling resonances, we may have to add six more correction magnets if θ_{rms} = 3 mrad is difficult to achieve. One may get an impression that the value $2\times\theta_{rms}$ = 6 mrad is an outrageously large value to consider and this impression may be fully justified. The intention here is to show that the correction system can handle up to this value. We have no idea how accurately the angle can be measured and how accurately it can be reproduced in the tunnel. Furthermore, there is no assurance that the change induced by warmup-cooldown cycles will be negligible. In the lowest order, systematic tilt of the magnetic axis does not contribute to the coupling parameter.

C. Tracking error of quadrupoles

This is the deviation from the design value of average $\int B' d\ell$ over all quadrupoles. The value $\int B' d\ell$ of at least one quadrupole must be measured accurately so that other quadrupoles can be compared with it.

Guideline $\quad |\Delta \int B' d\ell / \int B' d\ell| < 2.5\times 10^{-3}$

The error in ν_x and ν_y is then ±0.056. It is expected that the average quadrupole component in dipoles is

$$|b_1|_{av} \equiv |B'/B|_{av} = (0.5\sim 1.0)\times 10^{-4}/\text{inch}$$

which shifts tunes by ±0.057∿ ±0.11.

D. Variation of B' in each quadrupole (ΔB'/B')

This is a condition for the combined effect of all multipoles. In dipoles, the average normal quadrupole component at x = ±2cm is

$$|\Delta B'(\text{dipole, } x=\pm 2\text{cm})|_{av} \simeq 1.8\times 10^{-3}\times B'(\text{quadrupole})$$

where B'(quadrupole) = 19.3 kG/inch at 1 TeV/c.

Guideline $\quad |\Delta B'/B'|$ at $x = \pm 2$cm $< 2.5\times 10^{-3}$

E. Fluctuation of B' among quadrupoles

This contributes to the stopband width of resonances $2\nu_x = 39$ and $2\nu_y = 39$.

full resonance width (f.r.w.) = $7.5\times(\Delta B'/B')$

From dipoles, with twice the rms value of (B'/B), we have f.r.w. = .025.

Guideline $(\Delta B'/B')_{rms} < 1.5\times10^{-3}$

With twice the rms value, this gives f.r.w. = 0.023.

F. Sextupoles, Octupoles, and Decapoles

Multipole components in the quadrupole magnets are expressed in terms of $\bar{b}_n$ and $\bar{a}_n$:

$$B_y(y=0) \equiv B_o' \left(x + \bar{b}_2 x^2 + \bar{b}_3 x^3 + \ldots\ldots \right)$$

$$B_x(y=0) \equiv B_o' \left(\bar{a}_1 x + \bar{a}_2 x^2 + \bar{a}_3 x^3 + \ldots\ldots \right)$$

The median plane is defined such that $\bar{a}_1 = 0$. In order to compare with (b_n, a_n) of dipoles, quadrupole parameters $(\bar{b}_n, \bar{a}_n)$ should be multiplied by the factor B_o'/B_o=0.463/in. For various resonance widths and for the chromaticities, contributions from multipole components in quadrupoles are less than ten percent of those coming from multipoles in dipoles if $\bar{b}_n = b_n$ or $\bar{a}_n = a_n$.

(quadrupole contributiion/dipole contribution)

sextupole resonances $(\bar{b}_2, \bar{a}_2)$	0.075 ∿ 0.077
octupole resonances $(\bar{b}_3, \bar{a}_3)$	0.083 ∿ 0.084
decapole resonances $(\bar{b}_4, \bar{a}_4)$	0.089 ∿ 0.091

Guidelines $|\bar{b}_2| < 8\times10^{-4}$/inch, $|\bar{a}_2| < 5\times10^{-4}$/inch

$|\bar{b}_3| < 5\times10^{-4}/\text{inch}^2$, $|\bar{a}_3| < 5\times10^{-4}/\text{inch}^2$

$|\bar{b}_4| < 4\times10^{-4}/\text{inch}^3$, $|\bar{a}_4| < 4\times10^{-4}/\text{inch}^3$